

Study of the Quality Factor of a Niobium SRF Cavity

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Basics of SRF Cavities

- **Superconductivity:**
 - Absence of electrical resistance below T_c
 - Perfect diamagnetism (“Meissner Effect”)
 - Surface resistance R_s & “Two-fluid Model”
- **Superconducting vs. Conventional RF:**
 - Lower surface resistance → Lower power loss
 - Why Nb: Highest T_c (9.25 K) and B_{c1} (200 mT)
- **Applications:**
 - Lower operating cost in a CW machine (e.g. ERL)
 - Higher E_{acc} in a pulsed machine (e.g. ILC)
- **Quality Factor:**
$$Q_0 = \frac{\omega_0 U}{P_c} = \frac{\omega_0 \mu_0 \int_V |H|^2 dv}{R_s \int_S |H|^2 ds} = \frac{G}{R_s}$$

Q curves & Surface resistance

- Study the effects of different cavity treatments on Q curves: Low, medium and high field Q slopes

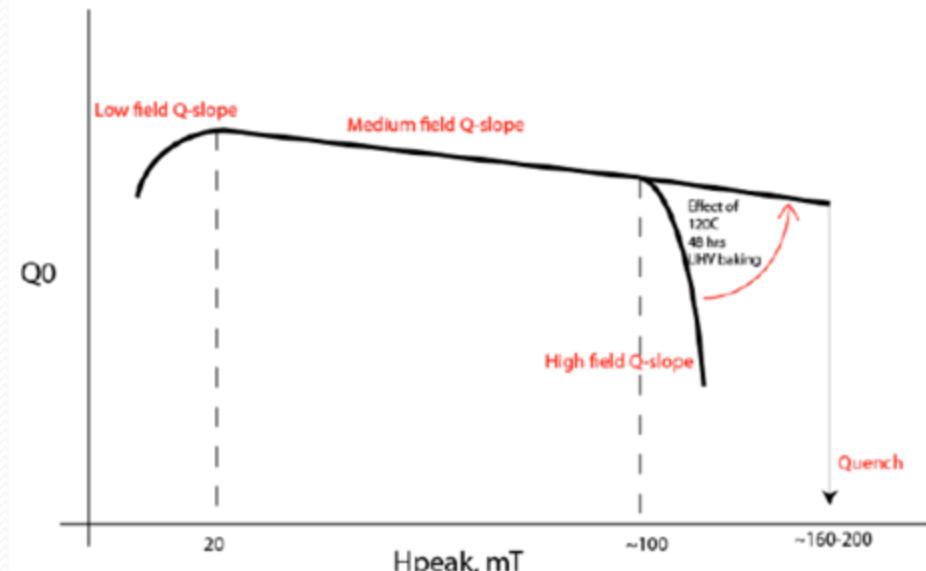
- BCS theory & Cooper pairs

$$R_s(T) = R_0 + R_{BCS}(T)$$

- Sources of R_o :

- Trapped magnetic flux
- Hydride (“Q-disease”)
- Oxide

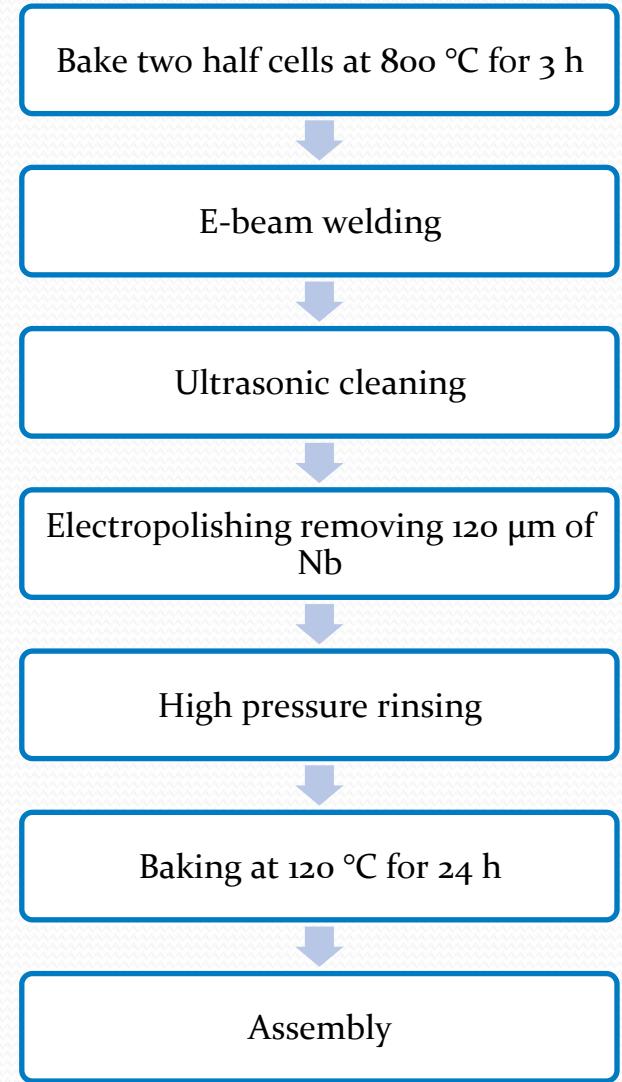
$$R_{BCS}(T) = A \left(\frac{1}{T}\right) f^2 e^{-\frac{\Delta(T)}{kT}}$$



- Study microscopic parameters from simulation

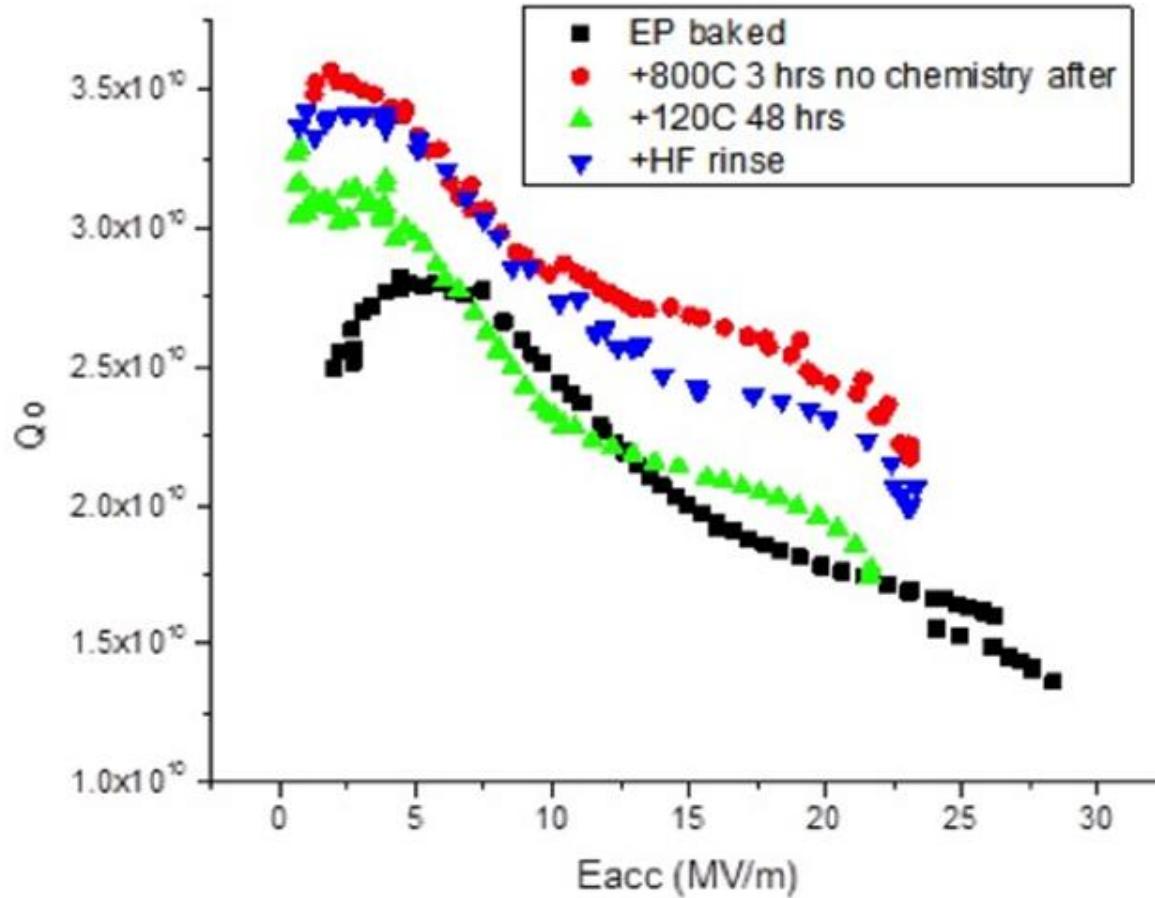
Experimental set-up

- TESLA-shaped large-grain single-cell cavity (TE₁AES₀₁₆)
 - 1.3 GHz in TM₀₁₀ mode, G = 270 Ω
- **Baseline treatment**
- **Cavity tests:**
 1. Q_o vs. E_{acc} measurement
 2. Q_o vs. T measurement (2 K ~ 1.53 K) at E_{acc} = 5 MV/m
 3. Cavity treatment and repeat 1 & 2



Cavity treatment

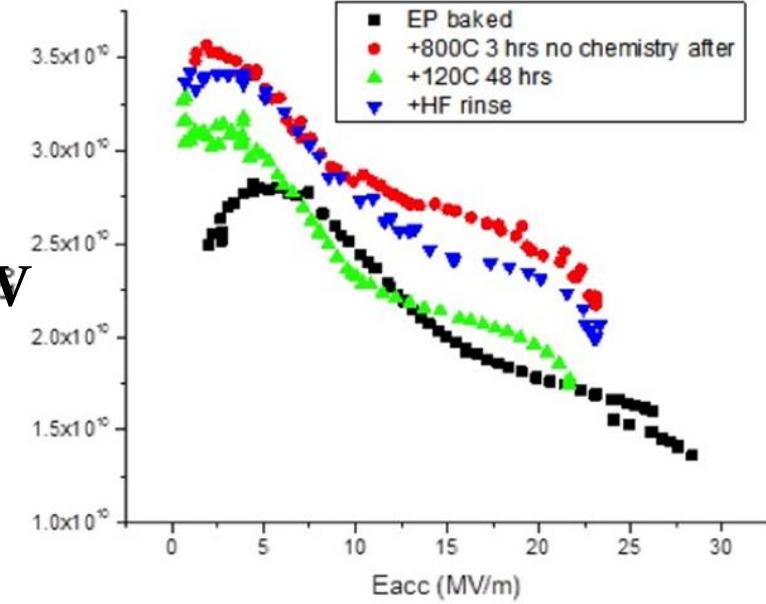
- Cav



: 1 atm

Experimental results & discussion

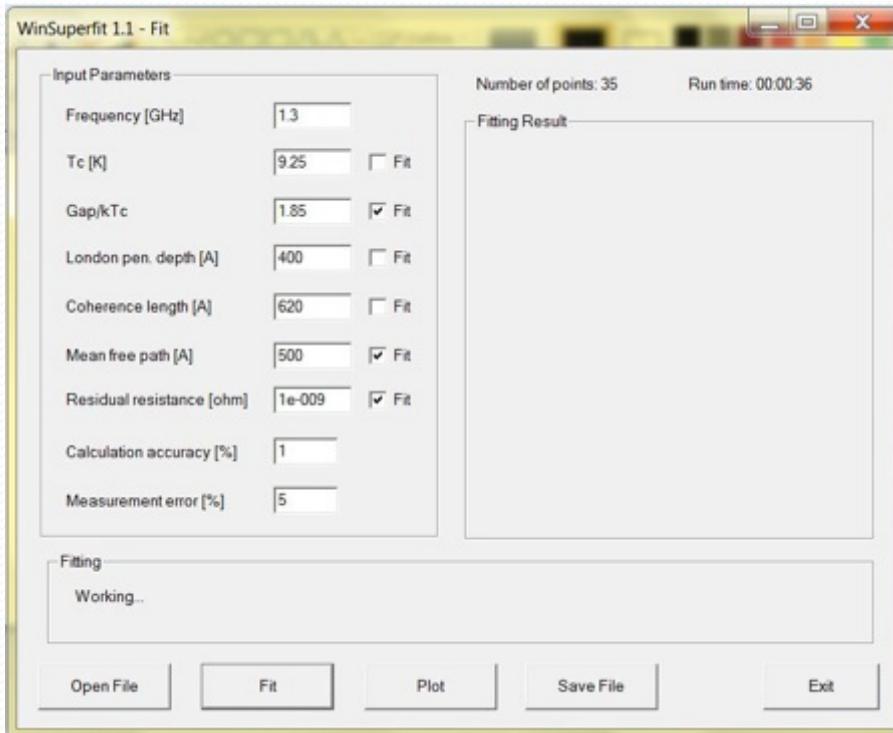
- After baseline treatment:
 - ❖ *Absence of high-field Q drop*
- After baking at 800 °C for 3 h in UHV
 - ❖ *Low-field Q increase disappears*
 - ❖ *Earlier quench at around 22 MV/m*
(earlier thermal breakdown due to lower RRR and lower thermal conductivity)
 - ❖ *Entire Q curve shifts up*
- After baking at 120 °C for 24 h in UHV
 - ❖ *Entire Q curve shifts down*
- After HF rinse
 - ❖ *Entire Q curve shifts up*



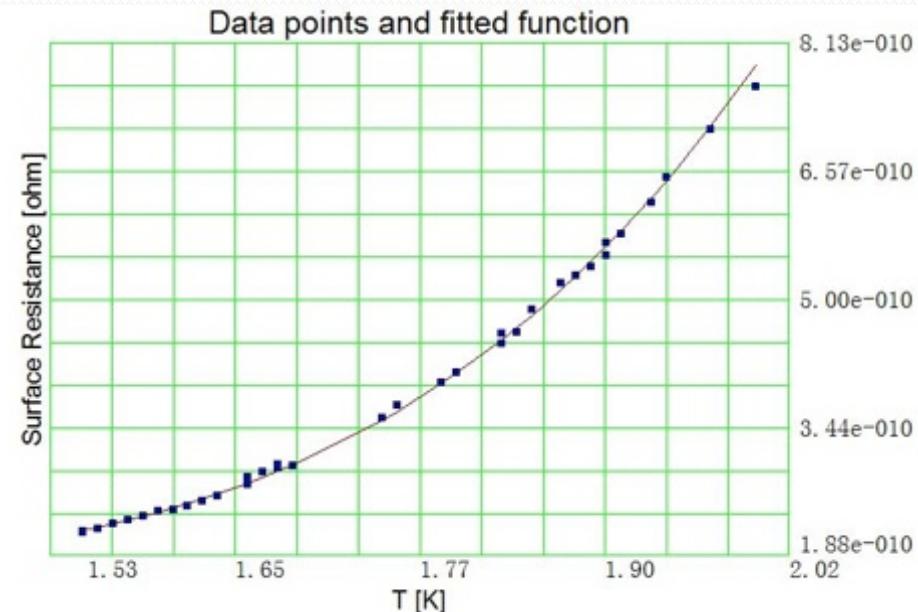
Extracting microscopic parameters from R_s vs. T measurement

$$R_s = f(T_c, \xi_0, \lambda_L, \Delta, l, R_0)$$

fixed fit



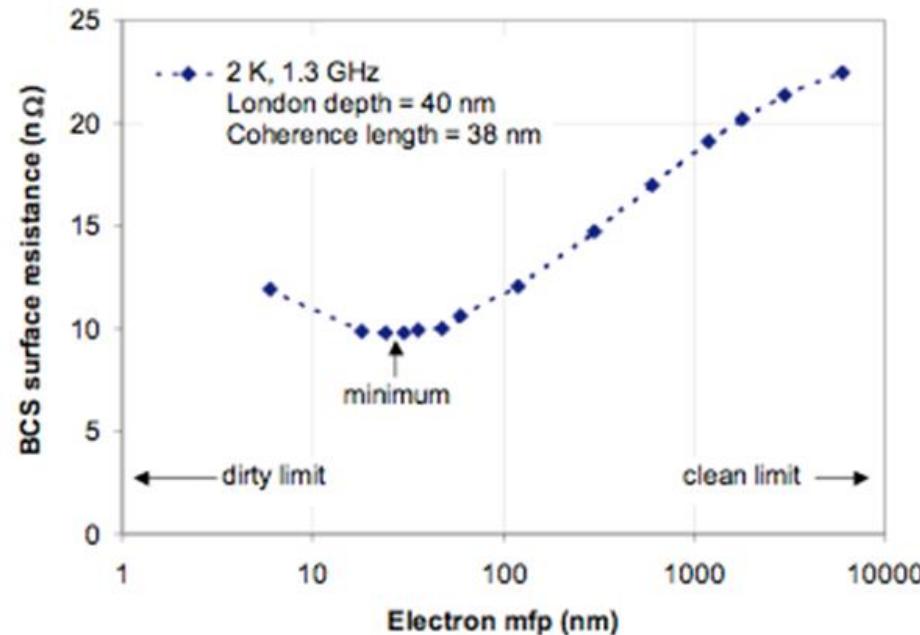
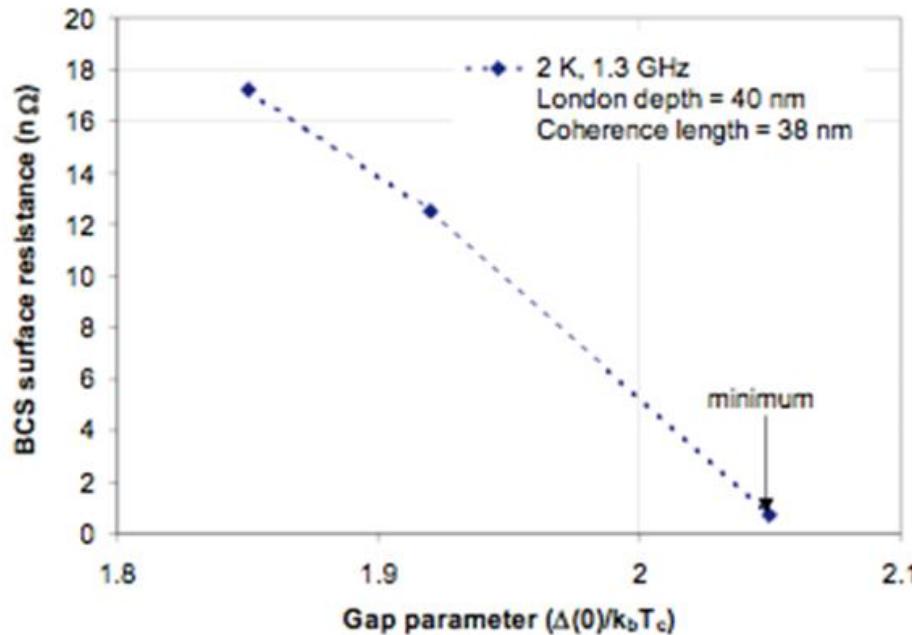
Program interface



R_s vs. T (experimental)

Results from the fit

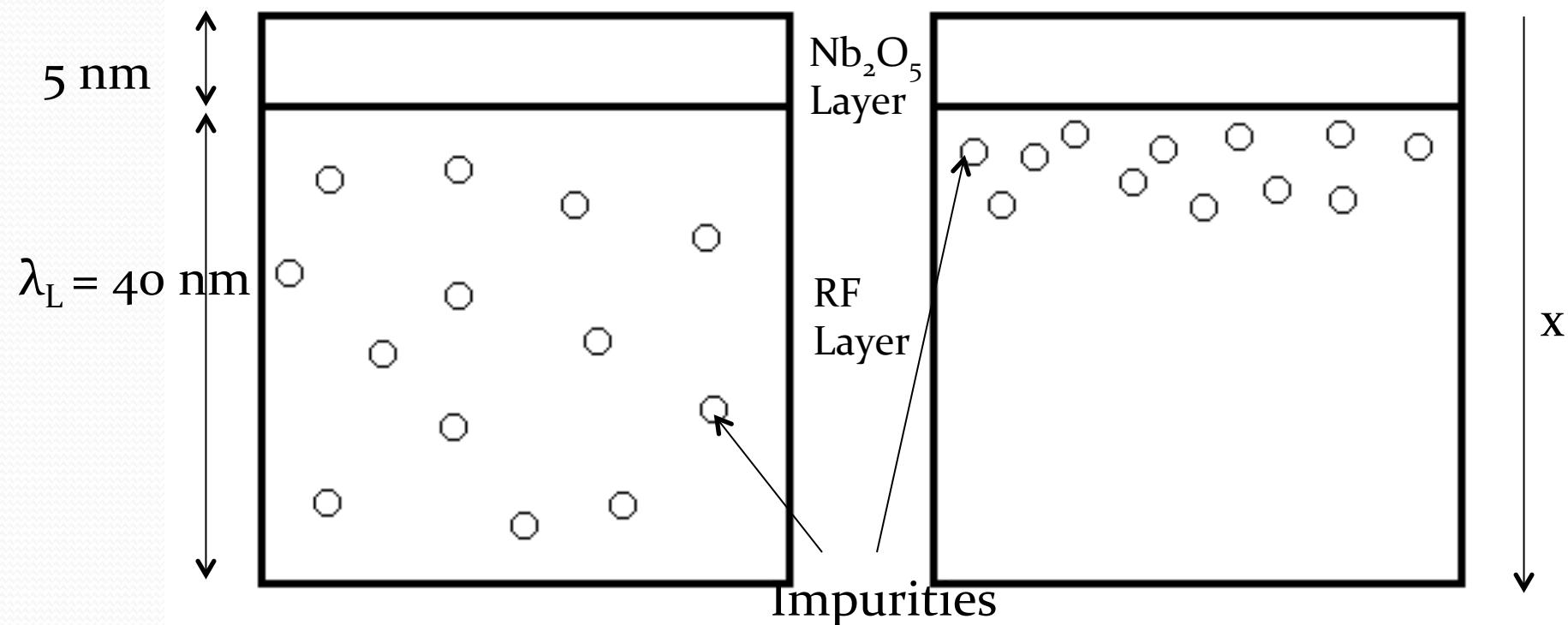
	I (\AA)	Δ (kT_c)	R_0 (Ω)	R_{BCS} (Ω)	R_s (Ω)
Baseline	225.407	1.96341	4.04E-09	6.49E-09	1.05E-08
After 800 C	247.936	1.94803	1.64E-09	6.21E-09	7.85E-09
After 120 C	246.531	1.90669	1.64E-09	8.14E-09	9.77E-09
After HF rinse	250.886	1.88686	7.38E-11	1.04E-08	1.05E-08



Model to explain change in R_0

- Diffusion of impurities
- 120°C gathers the impurities at the very near surface (first few nanometers) → increase in R_0 , higher if starting layer is ‘dirtier’ (i.e. after EP), less pronounced effect if starting layer is ‘cleaner’ (i.e. after 800°C)
- EP + 120°C vs. $800^\circ\text{C} + 120^\circ\text{C}$ – more vs less impurities in the RF layer
- HF rinse removes first few nanometers → removes lossy layer leaving almost zero R_0

$$B(x) = B_0 \exp\left(-\frac{x}{\lambda_L}\right),$$



Conclusion & Acknowledgement

- Worked on:
 - Understanding of SRF cavities & cavity tests
 - Study of the change of performance with different treatments
 - Simulations with a fitting program to extract microscopic parameters after each treatment
 - Possible model for physical mechanisms happening at the surface
- Acknowledgement:
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